2012 International Conference on Environment, Energy and Biotechnology
IPCBEE vol.33 (2012) © (2012) IACSIT Press, Singapore

Selection of CO_2 Control Technology For Cement Industry Using Analytic Hierarchy Process

Mohammed Ba-Shammakh

Chemical Engineering Department, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia

Abstract. The cement industry is considered to be one important large point source of CO_2 emissions. So, it is important to develop and implement effective control strategies to reduce CO_2 emissions from the cement industry. Any control strategy must be selected based on certain criteria. Analytic hierarchy process (AHP) technique is used as a decision support tool to find the best technology for CO_2 emissions based on multi-criteria. These criteria are; cost, efficiency, duration and number of previous applications in cement plants. The results show that installation of high efficiency motors and drives technology will be selected if cost is the criterion of selection. However, CCS technology is the choice under two criteria which are efficiency and duration. Technology of switching to lower carbon content fuel will be recommended if number of applications in cement plants is the criterion of selection.

Keywords: Analytic hierarchy process, Cement industry, CO_2 reduction, Carbon Capture

1. Introduction

Economical and industrial developments are expected to be accompanied by an increase in greenhouse gas emissions, mainly CO_2. The cement industry is among the industries that release the most CO_2 to the atmosphere. It is reported in literature that for each tonne of Portland cement (an essential component of concrete) produced, approximately one tonne of CO_2 is emitted to the atmosphere [1, 2]. The cement industry generates approximately 5% of the global anthropogenic CO_2 emissions [3]. This is mostly due to combustion at the manufacturing operations, transportation, and combustion of fossil fuel required to produce the electricity consumed by the cement industry. Environmental policies related to CO_2 emissions can potentially affect greatly the cement industry.

Cement is formed by burning ground raw materials in a kiln to form a clinker and grinding the clinker with a small addition of gypsum to produce a fine grey powder. However, there are two main steps to producing cement: the production of clinker, and its cooling, grinding and blending. Portland cement is usually made of limestone ($CaCO_3$), silicon oxides (SiO), aluminum, and iron oxides. These materials are quarried, crushed, ground, blended, and burned at 1500–2000°C, in either rotary or shaft kilns. There are two processes (one wet and one dry) for producing clinker, which is the most energy-intensive step. The dry process is more energy-efficient. In modern kilns, raw materials are preheated using waste heat [4].

2. CO_2 Emissions in Cement Industry

The main sources of carbon dioxide in cement manufacturing are combustion of fossil fuel and limestone calcinations. The most common fuels are coal, petroleum coke, fuel oil and natural gas. Currently, the cement industry in North America and Europe base its fuel choice on three basic factors: cost, product quality, and environmental impact. The fuel that best fills these three basic requirements will be the preferred choice. It is important to note that factors such as the cost of a new firing system, the amount of storage, and local fuel availability also play a key role in the decision process.There are other sources for CO_2 emissions in a cement plant, such as electricity and mobile equipments. These represent, however, a small contribution to the total CO_2 generated by the cement manufacturing. Approximately, half of the CO_2 emitted by the cement industry originates from the fuel and half from the calcinations. [1,2]

Analytic Hierarchy Process (AHP) technique will be used to select the best control option for CO_2 in cement plant under different criteria. The AHP, developed by Saaty [5, 6, 7 & 8] is a decision making method for prioritizing alternatives when multiple criteria must be considered. The primary advantage of the AHP is its use of pairwise comparisons to obtain a ratio scale of measurement. Ratio scales are a natural means of comparison among alternatives and enable the measurement of both tangible and intangible factors. An AHP analysis uses pairwise comparisons to measure the impact of items on one level of the hierarchy on the next higher level. At each level, the pairwise comparisons are organized into a matrix and the weights of the items being compared are determined by computing the maximum eigenvalue of the matrix. A weighted averaging approach is used to combine the results across levels of the hierarchy to compute a final weight for each alternative. Weights, in the AHP are determined using pairwise comparison between each pair of criteria as explained earlier. Each comparison is transformed to a numerical value (see Table 1 which is developed by Saaty [5, 6]). The result is a positive reciprocal matrix $A=\{a_{jk}\}$ with $a_{kj}=1/a_{jk}$, where a_{jk} is the numerical equivalent of the comparison between criteria j and k. The normalized weight vector, $w = (w_1, \ldots, w_N)$, is obtained by solving the equation $Aw = e_{max}w$, where e_{max} is the largest eigenvalue and w is a normalized eigenvector associated with A and e_{max}.

Table 1: Pairwise comparision values comparing criteria j and k [5]

Value a_{jk}	Comparison description
1	Criteria j and k are of equal importance
3	Criterion j is weakly more important than k
5	Criterion j is strongly more important than k
7	Criterion j is very strongly more important than k
9	Criterion j is absolutely more important than k
2, 4, 6, 8	Intermediate
reciprocal	Less important

A top-down or bottom-up analysis is carried out for the construction of the hierarchy tree, depending on the available data and the in-depth knowledge available for the alternative options and the criteria. Then criteria weights and alternatives scoring against each criterion should be assessed. The hierarchy tree is constructed with the goal at the top level.

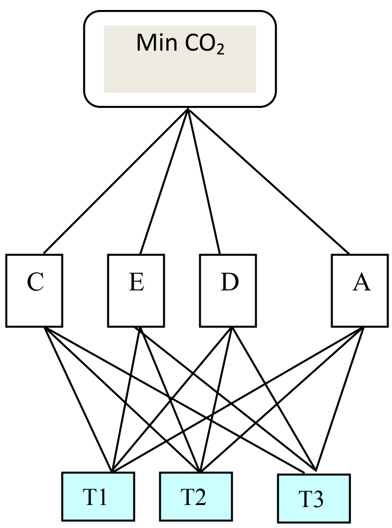

Fig. 1: Hierarchy tree

The goal is to choose a technology to minimize CO_2 emissions under the four criteria shown in the figure and these are:

- Cost of the technology (**C**)
- Efficiency of the technology (**E**)
- Lifetime or duration of the technology (**D**)
- Applicability of the technology (**A**)

Some of the technologies that can be used to reduce CO_2 and considered in this study are:

- Installation of high efficiency motors and drives (**T1C**)
- Installation of efficient grinding technology (**T2C**)
- Switching to lower carbon content fuel (**T3C**)
- Carbon capture and sequestration (CCS) (**T4C**)

3. Results and Discussions

There are four factors or criteria that are used to select a technology for each CO_2. Preferences of these factors are shown in a matrix below (Table 2) and the eigenvectors are also shown as the last column to rate these criteria in terms of importance to decision makers. The table used the Saaty's approach in comparing the criteria.

Table 2: Pairwise comparison between the four criteria

	C	**E**	**D**	**A**	**n^{th} root of product of values**	**Eigenvectors λ**
C	1	1/3	3	3	1.32	0.28
E	3	1	3	3	2.28	0.48
D	1/3	1/3	1	1/3	0.44	0.092
A	1/3	1/3	3	1	0.76	0.16
				Total	**4.8**	

Table 3 shows the results for CO_2 pollutants and it recommends the technology T1C which is installation of high efficiency motors and drives if cost is the criterion of selection. However, CCS technology (T4C) is the choice under two criteria which are efficiency and duration. Technology of switching to lower carbon content fuel (T3C) will be recommended if number of applications in cement plants is the criterion of selection.

Table 3: Summary of eigenvectors for CO_2 control

technology	**C**	**E**	**D**	**A**
T1C	**0.56**	0.05	0.097	0.13
T2C	0.26	0.08	0.097	0.015
T3C	0.12	0.37	0.35	**0.45**
T4C	0.08	**0.51**	**0.46**	0.41

The eigenvector for this case after considering the weight of the four criteria is:

$$\lambda_C = [0.21, 0.12, 0.32, 0.35]$$

This means that CCS technology by MEA (T4C) is recommended considering all four criteria and Figure 2 shows the technologies ranking for CO_2 reduction.

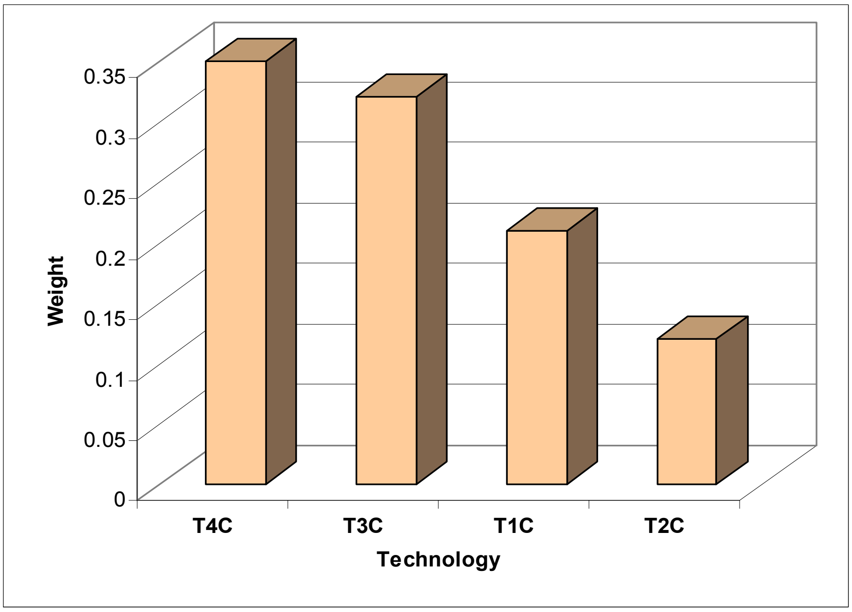

Fig. 2: Technologies ranking for CO_2 reduction

4. Acknowledgements

The author would like to thank King Fahd University of Petroleum & Minerals for its support in doing this study.

5. References

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